10/509861

DT09 Rec'd PCT/PTO 01 OCT 2004

TRANSLATION (HM-598PCT -- original):

WO 03/092,931 A1

PCT/EP03/02,384

ADJUSTMENT OF HEAT TRANSFER IN CONTINUOUS CASTING MOLDS, ESPECIALLY IN THE MENISCUS REGION

The invention concerns a mold for the continuous casting of molten metals, especially steel, with cooling channels, such as cooling grooves, cooling slits, or cooling bores, in the side of the mold that faces away from the melt contact surface.

A continuous casting mold, especially a CSP (compact strip production) mold of conventional design in the form of a plate mold, for the continuous casting of steel blooms or slabs is usually constructed with sidewalls, each of which consists of a support wall and an inner plate that is mounted on the support wall and comes into contact with the molten metal. Coolant channels that are parallel to one another are preferably provided on the side of the inner plate that faces the support wall and can be formed as slots that are open towards the support wall.

In CSP molds of current design, the heat transfer

conditions along the height of the mold can be varied within limits, especially in a region above and below the level of the molten metal. For example, the wall temperature of the mold can be reduced above the level of the molten metal. When the heat transfer is reduced in the area of the molten metal level and/or above the molten metal level, however, the temperature of the mold increases. This has the following advantages:

-- casting flux melts faster due to the hotter mold in the region of the molten metal level;

-- the faster melting of the casting flux improves the lubricating effect between the strand and the mold, which has the effect of improving the surface of the strand;

-- better lubrication leads to a lower mold surface below the molten metal level, which results in reduced thermal stresses and reduced cracking tendency and thus a higher service life of the mold; and

-- hotter regions of the mold above the molten metal level reduce the compressive stresses in the regions below the molten metal level; this also reduces cracking and prolongs the service life of the mold.

It is known from measurements on continuous casting molds

that the distribution of the heat flux densities has a maximum 20-80 mm below the molten metal level and then decreases in the manner of a bell curve both in the casting direction and in the opposite direction. The region of increased heat flux density is about 120 mm long.

An associated graph of the temperature distribution of the melt in the mold corresponds to the curvature of a horizontal parabola with t_{max} in the region of the increased heat flux density.

The document DE 38 40 448 C2 describes a continuous casting mold, especially a plate mold, each of whose sidewalls is formed by a support wall and an inner plate, which is mounted on the support wall and is in contact with the molten metal, and wherein parallel coolant channels are provided on the side of the inner plate facing the support wall and are formed as slits that are open towards the support wall. The width of these slits is smaller and their depth greater than the width of the ribs between the slits.

EP 0 551 311 B1 describes a liquid-cooled, adjustable-width plate mold for the continuous casting of steel strands in slab format, especially in a thickness of less than 100 mm. In this

mold, the transverse dimensions of the broad-side plates and narrow-side plates are designed for the purpose of increasing the cross section of the strand, the narrow-side plates being arranged essentially parallel to each other over the height of the mold, whereas the broad-side plates are concave at least in the region where the slab is at minimal width, in such a way that, in cross section, the height of the highest point of the curved mold wall reaches a maximum of 12 mm per 1,000 mm of slab width relative to an inscribed rectangle on the inlet side of the mold, and where the shape of the broad-side plates at the strand exit end of the mold corresponds to the shape of the strand to be produced. The broad-side plates are flat in the area where the narrow-side plates can be adjusted, and slit-like channels are arranged in the side that faces away from the shaping side.

EP 0 968 779 A1 pertains to the formation of the broad side of a slab mold with a casting plate with an inner surface and an outer surface opposite the inner surface, such that the broad side has an upper and a lower region, and such that at least the upper region has a middle region and two lateral regions arranged on either side of it. The cited document proposes that

the inner surface of the casting plate be provided with undercut grooves to form cooling channels, and that the grooves be covered in a positive-locking way by fillers, which are inserted into the undercuts.

US Patent 5,207,266 pertains to a water-cooled copper mold, which comprises a copper plate with a back frame fastened to it to form cooling channels, where the widths of the main channels are greater in the bolt-fastening areas than they are in the other areas. The design of the mold calls for larger channels between the channels on the right and between those on the left of the mounting bolts, excluding the screwed joints. Branch channels between the main channels and the enlarged channels are provided, where at least the branch channels and the branch areas of the main channels have larger water surface areas than the main channels and the enlarged channels do.

Intensive cooling, i.e., heat dissipation, from the region between the meniscus and the outlet of the mold is essential for the rapid and reliable formation and especially for the uniform formation of a crack-free strand shell. The following possibilities exist for this in previously known molds:

-- setting the cooling water flow rate to a relatively high

value;

-- reducing the temperature of the cooling water; and

-- enlarging the heat-exchange surfaces in the cooling channels by the use of cooling fins.

The aforesaid variants are already being used frequently in practice in the design of molds for continuous casting plants.

The contact plate of the mold, which generally consists of a copper alloy, is in ``direct contact'' with the molten and solidified metal. The contact plate, which is also referred to as the copper plate, is a part that is subject to wear and is mounted on a support, which is usually made of steel. This reusable support is called a water box.

The mold itself acts as a crystallizer; i.e., so much energy is removed from the introduced molten steel that a load-bearing strand shell forms, which can then be continuously withdrawn from the mold. Under these conditions, a first strand shell forms at the height of the filling level in the mold, i.e., at the so-called meniscus. The term ``meniscus'' is applied to the region where the strand shell first forms; this is the region where the contact surface of the mold, the solid and molten casting aids, the molten steel, and the strand shell

meet. Casting fluxes and oils are used as casting aids. They separate the metal and the copper from each other by lubrication and control the local heat transfer (Figure 8).

The first volume element of the strand shell formed at the meniscus migrates through the mold at the take-off speed. On the basis of the given temperature gradient between the molten steel and the coolant, a local energy flux develops in the direction of the cooling channels. Its energy content is removed through the cooling channels, through which the coolant, usually water, flows. The thickness of the strand shell increases accordingly.

The cooling channels formed in the mold structure can be either completely within the copper plate or completely within the water box component. Combination designs are also known. In addition, there are standard variants in which filler pieces are installed between the water box and the copper plate to form suitable cooling channels.

For reasons related to manufacturing technology, cooling channels with rectangular or circular cross sections are very common. Corner regions can be rounded. However, U-shapes, L-shapes, and T-shapes of any desired orientation relative to the

contact surface can also be produced by suitable filler pieces. The cooling channels, arranged either individually or in groups, typically proceed in the casting direction, i.e., from top to bottom, and they are usually equidistant from the contact surface. The goal of these efforts is to achieve a cooling effect through the contact surface of the mold that is as homogeneous as possible, which is often successful to only a limited extent in the area of the fastening points. Cooling channels with different cross sections and/or geometric shapes are often placed side by side to optimize further the uniformity of the cooling effect over the casting width (Figure 10).

All of these designs have in common the property that the geometry of an individual cooling slit remains the same with respect to shape and cross-sectional area along its entire length. As a result of this design, the cooling channel surface area that can be utilized for cooling remains unchanged along the length of the cooling channel. It can also be deduced from the quantitative balance along an imagined flow path that the flow rate remains constant along the entire length of the cooling channel.

There is only one special design for cooling channel bores

which attempts to deal with this problem. In this design, central displacement pins can be inserted from above or below. Since the length of the displacement pin is usually shorter than the bore itself, a cross-sectional constriction occurs in the cooling channel, which leads to an acceleration of the coolant in this transition zone. In the narrowed cross-sectional region, the coolant then flows faster, which intensifies the cooling effect correspondingly. However, the effective cooling surface for the cooling channel remains unaffected by this measure.

The cooling channel designs that have been customary until now are aimed at a cooling effect that is as homogeneous as possible, and in these designs, no consideration is given to the inhomogeneous thermal load distribution actually present on the mold plate. On the basis of the analysis, which is necessarily multidimensional, two in homogeneities in the thermal load distribution are to be distinguished:

-- the inhomogeneity parallel to the casting direction; and

-- the inhomogeneity perpendicular to the casting direction.

In the casting direction, the heat transfer from the molten

steel to the coolant in the cooling channel can be analyzed in a simplified way as one-dimensional heat conduction through several layers. The following terms must be considered in the energy balance equation:

1. heat transfer from the molten steel to the strand shell that has formed,

2. heat conduction by the strand shell,

3. heat conduction by the lubricant layer,

4. heat conduction by the copper plate, and

5. heat transfer to the coolant.

Expansion terms do not have to be considered in the steady-state case.

One cause of the nonuniform thermal load distribution over the length of the mold is contained in the term of heat conduction by the strand shell, since a strand shell forms first of all in the meniscus and continues to grow in the casting direction. The heat transfer thus decreases with increasing thickness of the strand shell. Therefore, if all the other parameters remain constant, it is to be expected that the heat flux has its highest value at the meniscus and then decreases continuously in the casting direction. A mean heat flux can be

derived by integration over the entire length of the cooling channel. Due to the multidimensionality of the heat conduction, i.e., no heat input occurs above the meniscus, the theoretically sharp curve of the heat flux density will be smoothed, and the position of the maximum will shift in the casting direction (Figure 9).

Operating measurements of local heat flux densities establish that the local values in the meniscus region can be 1.5 to 3 times higher than the mean heat flux, while the values at the mold base can be 0.3 to 0.6 times lower. The maximum is located 20-70 mm below the actual position of the meniscus, depending on the plant and the process parameters. The absolute values of the mean heat flux densities depend on the casting flux and especially on the casting rate. For example, mean heat flux densities that have been published are around 1.0 MW/m^2 at a casting speed of 0.9 m/min; 2.0 MW/m^2 at 3.0 m/min, and 3.0 MW/m^2 at 5.5 m/min. The local heat flux densities to be expected can at least be estimated by using these factors.

The nonuniform distribution of the heat flux density in the casting direction causes the primary thermal wear of the mold plate to occur almost exclusively in the meniscus region. This

manifests itself in scoring, cracking, deformation, and even flaking of layers that may have been applied earlier.

The load on the mold plate is also highly variable in the lateral direction. Inhomogeneities usually result from the molten steel flow field that develops in the mold. The processes are closely linked to the geometric design of the steel submerged nozzle which introduces the steel, to the contact surface geometry, and to other process variables. Steady-state and non-steady-state processes at the meniscus cause a usually plant-specific inhomogeneous development of the meniscus. The inhomogeneous development of the meniscus is also associated with an inhomogeneous heat distribution, so that the primary damage does not develop uniformly over the width of the mold but rather becomes concentrated in certain places.

Proceeding from the prior art specified above, the objective of the invention is to adjust the heat transfer, which is the determining factor for the cooling effect of the cooling channels, to the local heat flux density of the contact surface of the mold that is in contact with the molten metal by means of a special geometric design of the heat-transfer surface areas of a cooling channel or a group of cooling channels.

This objective is achieved by the invention in accordance with the features of Claim 1.

Further means of influencing the heat transfer in accordance with the invention are specified in the dependent claims. In this regard, it is possible, for example, to influence the local cooling effect of a channel by local variation of the channel's shape, cross-sectional area, circumference, boundary surface properties, orientation, and arrangement relative to the contact surface.

In addition, it is possible, for example, to increase or decrease the effective heat-exchange surfaces at the base of the channel or on the sidewalls.

For example, the surface area of the base or lateral surfaces of the cooling channels is significantly increased, nearly doubled in fact, by the formation of scores in the base or lateral surfaces, which results in a higher heat flux density with a considerably more intensive cooling effect at the same flow rate of the coolant. This has the important advantage that the temperatures of the mold are considerably reduced, so that it is possible to reduce not only the stress on the mold material but also the water pressures for the cooling water.

For example, comparative temperature calculations yielded the following values:

-- smooth surface of the heat-exchange surface at the base of cooling grooves (°C):

507° temperature facing the strand ;	173° temperature facing the water;

-- increased surface in accordance with the invention:

462° temperature facing the strand ;	131° temperature facing the water;
-45° difference	-42° difference.

The numbers clearly demonstrate the positive effect of the measure of the invention. Artificial enlargement of the cooling channel surfaces can also be realized in drilled CSP molds, preferably in the meniscus region, with the use of a broaching tool.

Other refinements of the invention are specified in other dependent claims. In this regard, the artificial enlargement of the cooling channel surface is not undertaken above the level of the molten metal, because in this region of the mold, it would be preferable to reduce the heat transfer to promote the melting of the casting flux.

A reduction of the heat transfer above the molten metal

level is achieved by:

-- insertion of sleeves in cooling bores above the molten metal level;

-- coating the bores above the molten metal level; and

-- introducing inserts made of a material of lower thermal conductivity above the molten metal level.

At the same time, a hotter region of the mold above the molten metal level reduces stresses in the mold and thus reduces cracking of the strand and simultaneously increases the availability of the mold.

In this regard, it was found to be especially advantageous to use the measure of adapting the amount of heat being dissipated via the heat-transfer surface areas of the cooling channels to the heat flux density distribution in the channels in a manner which varies along the height of the mold.

This evens out the temperature gradients in the mold along the height of the mold even more, avoids relatively large material stresses in the strand shell that is starting to form, and prevents the formation of cracks in the strand shell.

The invention is explained in greater detail below with reference to specific embodiments:

-- Figure 1 shows an enlarged cross section of part of a mold wall perpendicular to its main dimension;

-- Figure 2 shows another cross section of part of the mold wall according to Figure 1;

-- Figure 3 shows cooling channel bores with scores on their inner surfaces;

-- Figures 4 and 5 show corresponding parts of heat-exchange surfaces without and with an enlarged base surface;

-- Figure 6 shows the behavior of the heat flux density q as a function of the height H of the mold below the molten metal level;

-- Figure 7 shows a graph of the depth of the furrows R as a function of the height of the mold with the associated behavior of a temperature curve T, likewise below the molten metal level with T_{max} above and below the meniscus region;

-- Figure 8 shows a cross section of part of a mold wall with cooling channels and the associated heat flux;

-- Figure 9 shows two graphs side by side for comparison with the mean or overall heat flux density and temperature;

-- Figure 10 shows parts of coolant channels with the formation of comparable heat-exchanger bases;

-- Figure 11 shows additional designs of heat-exchanger bases; and

-- Figure 12 shows a distribution, adapted along the height of the mold, of the heat flux density distribution with q_{max} below the molten metal level.

Figure 1 shows an enlarged view of a part 10 of a side 2 of a mold wall that faces away from the melt with a slit-like cooling groove 1 formed in it. The cooling groove has a width B and a depth T. In accordance with the invention, the base region of the cooling groove 1 is formed with a profile that has scoring 3, which approximately doubles its surface compared to a planar design, e.g., as shown in Figure 4.

The heat dissipation of the heat-transfer surface areas of the cooling grooves, slits, or bores can be adapted to the heat flux density distribution of the mold in a manner which varies over the height of the mold, as is shown, for example, in Figure 6.

For this purpose, it is provided that the scoring 3 has a variable depth 4, of, for example, 1-4 mm and a dihedral angle of 30-60° between adjacent scores for the purpose of varying the intensity of the heat transfer, as shown purely by way of

example in Figure 7. The scores 3 can be formed with a dihedral angle of up to about 60°, with a height of up to about 4 mm, and with a spacing ``A'', thus resembling the profile of a screw thread. Naturally, scoring with other shapes can be provided to enlarge the cooling surface, e.g., wave-shaped, trapezoidal, dentiform, or the like.

Figure 2 shows a part 10 of a mold wall, which comprises a section of a support wall 5 and a section of an inner plate 6, which are tightly joined together, preferably screwed together. The inner plate 6 is penetrated by cooling channels 7, which are formed as slits that are open towards the support wall 5 and are covered by the support wall 5. In accordance with the invention, the bases of the slits are provided with heat-exchange surfaces 3, in which scores are provided to produce an artificially increased heat flux density.

Figure 3 shows an arbitrary section 10 of a mold wall with cooling channel bores 8 arranged therein, which have inner walls 9 provided with grooves or scores 3.

On the basis of the schematically indicated parts of coolant channels 7, 7' with heat-exchanger bases 11 and 12, which are to be compared with each other, Figures 4 and 5 show a

smooth configuration 11 and a configuration consisting of scores 12 and the corresponding temperature values. The drawings show a clear reduction of the temperatures for the design with the scored base 12, the conditions under which the process parameters to be compared were determined being strictly identical.

Figure 6 shows a heat flux density distribution adapted along the height of the mold in accordance with the invention with q_{max} for a limited region below the molten metal level (bath). Correspondingly, the temperature curve T in Figure 7 shows a temperature maximum T_{max} between points 14 and 15 with R_{max} within the region 13 to 17 of variable depth R of the heat-exchange grooves. The heat-exchange grooves 3 begin at 13 at the height of the molten metal level. The maximum groove depth 4 is reached at point 14. This maximum groove depth continues as far as point 15, and then the groove depth is reduced to the original level as point 16 is approached.

Figure 8 shows a cross section of a broad-sidewall of a mold, which comprises a support plate 20 with a contact plate 18 mounted on it, a layer of casting aid, and a schematically suggested coolant channel 7, a strand shell 19 developing in the

casting direction, and the associated heat flux.

Supplementing Figures 6 and 7, Figure 9 shows graphs of the behavior of the local heat flux density/temperature compared to the heat-transfer cooling channel surface as a function of the position of the meniscus.

Figures 10 and 11 show different possible designs for the cooling slits, especially for their base region.

Figure 12 provides a tabular listing of:

-- the channel cross-sectional areas;

-- the effective cooling channel wall areas;

-- their distance from the contact surface; and

-- the resulting effective cooling effect

of the corresponding design modifications in Figures 10 and 11, wherein all values are relative values and are to be considered only examples.

List of Reference Numbers

1. cooling grooves
2. side facing away
3. scores
4. depth
5. support wall
6. inner plate
7. coolant channel
8. coolant bore
9. wall part
10. section
11. beginning of the heat-exchange scores at the height of the molten metal level
12. maximum groove depth
13. end of the maximum groove depth
14. end of the depth reduction of the grooves

15.-17. constant groove depth reached

18. contact plate, contact surface
19. strand shell
20. support plate